

Autonomous Observations of the Upper Ocean Stratification and Velocity Fields About the Seasonally-Retreating Marginal Ice Zone

John M. Toole
MS 21/354 Clark Laboratory, WHOI
Woods Hole, MA 02543
phone: (508) 289-2531 fax: (508) 457-2181 email: jtoole@whoi.edu

Richard A. Krishfield
MS 21/128 Clark Laboratory, WHOI
Woods Hole, MA 02543
phone: (508) 289-2849 fax: (508) 457-2181 email: rkrishfield@whoi.edu

Mary-Louise Timmermans
111 Kline Geology Laboratory, Yale University
PO Box 208109
New Haven, CT 06520-8109
phone: (203) 432-3167 fax: (203) 432 3134 email: mary-louise.timmermans@yale.edu

Sylvia T. Cole
MS 21/350 Clark Laboratory, WHOI
Woods Hole, MA 02543
phone: (508) 289-3805 fax: (508) 457-2181 email: scole@whoi.edu

Fredrik T. Thwaites
MS 18/ 101F Smith Laboratory, WHOI
Woods Hole, MA 02543
phone: (508) 289-3351 fax: (508) 457-2107 email: fthwaites@whoi.edu

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LONG-TERM GOALS

The PI group seeks to observe the upper Arctic Ocean using autonomous instrumentation and build understanding of the physical processes controlling the evolving thermohaline stratification, the ocean currents and air-ice-sea interactions on time scales of minutes to seasonal and longer.

OBJECTIVES

As a contribution to the Marginal Ice Zone DRI, this research element is designed to observe the seasonal evolution of the upper-ocean stratification, document the time-varying ocean currents and

characterize the turbulent ice-ocean exchanges of heat, salt and momentum as the sea ice cover retreats poleward in spring/summer.

APPROACH

The specific approach of this element of the MIZ DRI involved deployment of Ice-Tethered Profilers with Velocity (ITP-V) to sample the ocean and return those observations to the PIs in near-real time. The ITP-Vs provide the MIZ group with vertical profiles of upper-ocean temperature, salinity and horizontal velocity at 3-hour resolution, as well as direct vertical turbulent flux estimates from just below the ice-ocean interface several times per day. The ITP-V is a variant of the ITP system that has contributed to sustained observations of the Arctic Ocean below sea ice since 2004. The ITP concept is, in short, Argo of the Arctic - a play on the international program maintaining an array of profiling floats throughout the temperate oceans. Briefly, the ITP system consists of three main components: a buoyant surface instrument package that typically sits atop an ice floe, a weighted, wire-rope tether suspended from the surface package, and an instrumented underwater unit that travels up and down the wire tether (Figure 1). The surface electronics case sits within a foam body designed to provide buoyancy for the plastic-jacketed wire rope tether and end weight should the ice fracture or melt, and to provide modest protection in the event of ice ridging. The profiler unit (much like an Argo float in shape and size) mounts on the tether and cycles vertically along it. Via an inductive modem, raw sensor and associated engineering data files are relayed from the underwater vehicle to the surface buoy at the completion of each one-way profile, which then transmits them by satellite to a logger computer at WHOI. The ITP-V instruments add a multi-axis acoustic-travel-time current meter and associated attitude/motion measuring unit to the standard ITP sensor suite to make direct, 3-D observations of ocean flow (Figure 2, 3).

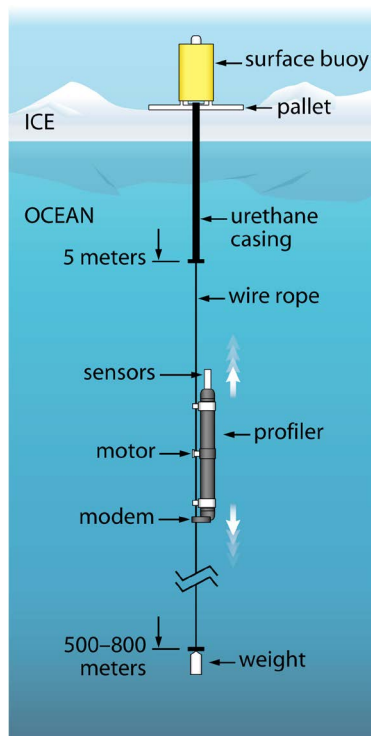


Figure 1. Schematic drawing of the Ice-Tethered Profiler instrument system.

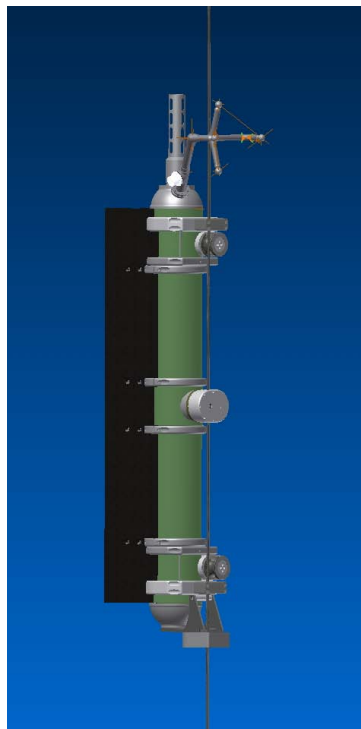


Figure 2. Engineering drawing of the Ice-Tethered profiler with Velocity.



Figure 3. Right. Photograph of an MIZ ITP-V being deployed (top) and in a test jig used to validate sensor orientations (bottom).

In preparation for the main field program, the PI's constructed and fielded one ITP-V in conjunction with the 2013 cruise of the Beaufort Gyre Observing System program (see <http://www.whoi.edu/beaufortgyre>) to test improvements made to the initial prototypes of the ITP-V instrument. For the main MIZ field program that began in Spring 2014, 3 ITP-V systems were deployed in an approximate north-south line spanning the seasonal sweep of the MIZ. Fellow MIZ investigators fielded complementary sensor systems in conjunction with the ITP-Vs. The Spring ice camp work was followed up with summer cruises to deploy drifting and mobile instruments to sample the ocean around the spring MIZ assets. In conjunction with that latter effort, a 5th ITP-V was deployed during the August cruise of *MV Araon*.

WORK COMPLETED

The MIZ fieldwork was detailed in last year's report. Sampling ended in May 2015, and the dataset is now complete. From the 5 ITP-V systems deployed in the program, Figure 4,, a total of 8,888 profiles and 3,840 fixed depth records were obtained over a total of 1,150 instrument-days of sampling. Temperature, salinity and absolute ocean velocity profiles were obtained from 6 m below the ice-ocean interface to 250 or 750 m depth. The fixed depth records were collected a few meters beneath the ice-ocean interface and used to estimate the vertical turbulent fluxes of heat, salt, and momentum. Hourly GPS fixes tracked the motion of the supporting ice floes and T/C recorders sampled the ocean waters just below the ice-ocean interface at 15-minute interval. Data processing has been completed following procedures detailed by Krishfield et al. (2008) for the CTD and Cole et al. (2015) for the velocity sensor. These products have been made available to fellow MIZ investigators. Near-real time handling of the velocity data has improved, and can be implemented for future ITP-V deployments. The MIZ ITP-Vs sampled in a range of ice conditions from full ice cover to nearly open water and observed a variety of stratification and ocean velocity signals (e.g., changes in mixed layer properties, internal wave energy levels, eddies, ...). Analysis of these data is underway.

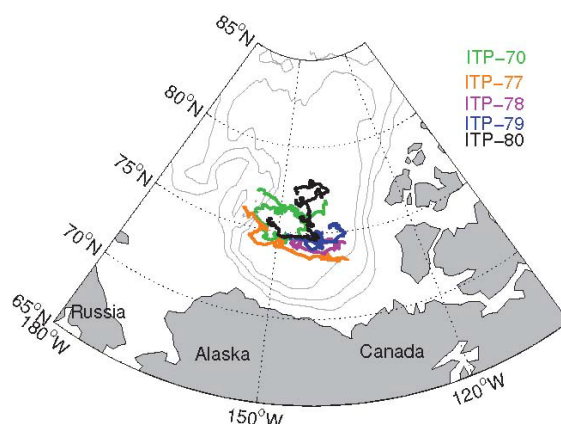


Figure 4. *Drift tracks of the 5 ITP-V systems deployed during the Marginal Ice Zone DRI program.*

RESULTS

Analysis of the MIZ ITP data is underway on multiple fronts. A few scientific highlights follow:

An undergraduate student from VIT University in India, Ratnaksha Lele, conducted a WHOI Summer Student Fellow Program investigation into sea ice dynamics and energetics using MIZ data under the supervision of Toole and Cole (Lele, 2015). Terms in the momentum and kinetic energy equations for ice floes were evaluated (apart from internal ice stresses that were derived as residuals) and the dominant balances assessed. On subinertial timescale, the dominant balances appear to be between wind stress/wind work driving ice motion and ice kinetic energy and ice-ocean stress/drag work resisting those motions and damping energy, Figure 5. At higher frequency, significant near-inertial variability was observed, particularly in summer when the ice concentration was reduced. Lele plans to present his research at the 2016 Ocean Sciences meeting.

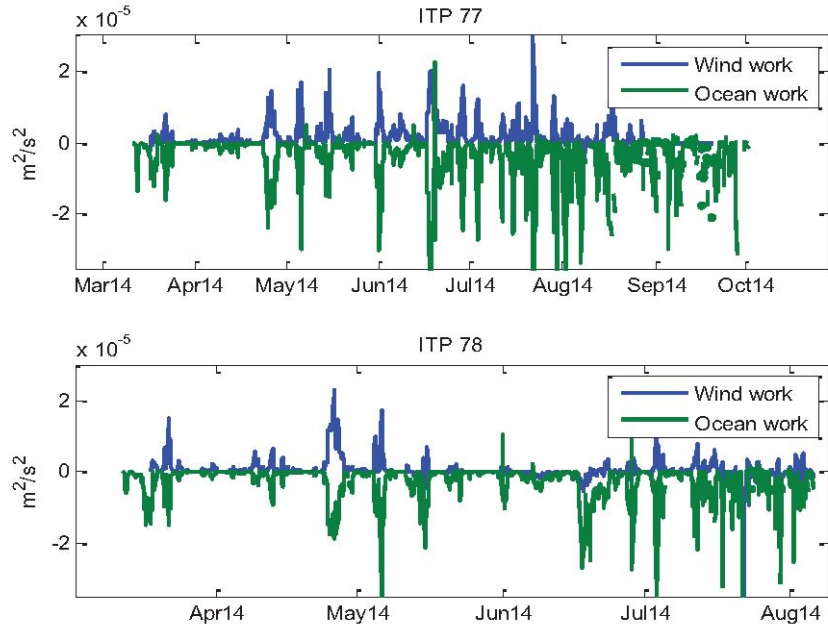


Figure 5. Time series of the wind stress work and the ocean stress work on sea ice floes supporting ITP-V systems during the MIZ program. Results from two systems (system numbers 77 and 78) are displayed. From Lele, 2015.

Yale graduate student Mengnan Zhao working with Timmermans is taking the lead analyzing mesoscale eddies across the full suite of ONR ITP-V measurements. This is a comprehensive analysis of their structure, energetics, and implications for vertical turbulent heat flux. Results to date indicate a particularly energetic mesoscale eddy field was in place during the MIZ experiment (Figure 6), with direct evidence for enhanced upper-ocean vertical heat fluxes above near-surface eddies. Zhao is taking the lead writing this work up for journal publication as a paper entitled "Energetics and implications to mixing of mesoscale eddies in the Canada Basin's marginal ice zone."

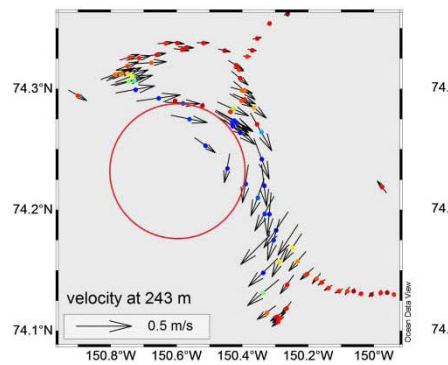


Figure 6. A map of ocean currents at 243 m depth associated with an anticyclonic eddy sampled by ITP # 77 during the MIZ program. The maximum velocity of the eddy is about 40 cm/s; the estimated eddy diameter of about 7 km was derived by fitting the measured velocity to a Rankine Vortex (red circle). From Zhao et al., in preparation.

Cole is leading the investigation into the ocean velocity and stratification variability observed by MIZ ITP-Vs. The internal wave field and associated velocity shear evolved during the focus period, with a seeming correlation with the concentration of overlying ice cover, Figure 7. The total energy in velocity shear was largest at ice concentrations less than 70%, consistent with the idea that more open water leads to increased internal wave energy. The primary increase in energy was associated with downward going internal waves (clockwise with depth velocity shear). The dominant vertical wavelength also shifted towards smaller scales as ice concentration changed from greater than 95% to 70-95%. This shift was independent of changes in the mixed layer depth, and possibly suggests that the smaller ice floes present at smaller ice concentrations generate internal waves with smaller horizontal (and consequently smaller vertical) scales.

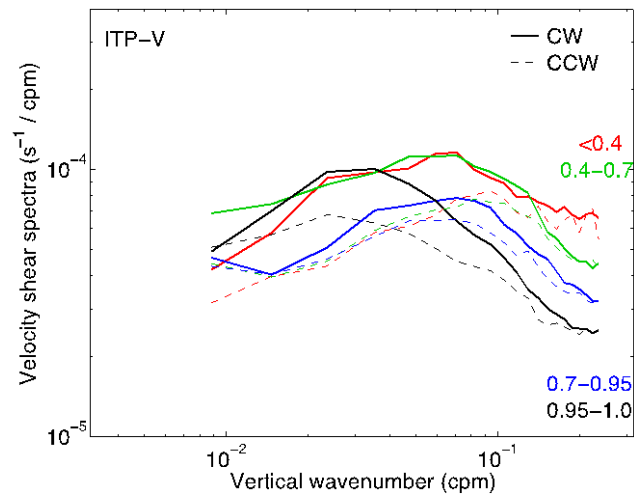


Figure 7: Vertical wavenumber spectra of velocity shear over 70-250 m depth from clusters 2-4 averaged by SSM/I ice concentration estimates. Clockwise with depth components are solid, counterclockwise with depth are dashed.

IMPACT/APPLICATIONS

Observations and insights deriving from the MIZ program will advance understanding of ice-ocean interactions and their parameterizations in numerical models. In turn, predictions and assessments of the future state of the Arctic Ocean will result.

Improvements to the velocity measurement system of the ITP-V developed under the present funding has applications to other instrument systems (such as the bottom-anchored Moored Profiler instrument).

RELATED PROJECTS

The present project, a component of the Marginal Ice Zone DRI (see <http://www.apl.washington.edu/project/project.php?id=miz>) is related to all of the companion MIZ projects. The closest connection is with the project "Acquisition of Ice-Tethered Profilers with Velocity (ITP-V) Instruments as a contribution to the Marginal Ice Zone DRI," Award Number: N00014-12-1-0799, that provided the ITP-V instruments.

REFERENCES

- Cole, S.T., F.T. Thwaites, R.A. Krishfield, and J.M. Toole, 2015. Processing of Velocity Observations from Ice-Tethered Profilers. Proceedings Oceans 2015 MTS/IEEE, Washington, D.C. Oct 19-22, [in press]
- Krishfield, R., J. Toole, and M.-L. Timmermans, 2008. ITP Data Processing Procedures, unpublished manuscript (Available from <http://www.whoi.edu/page.do?pid=23096>).
- Lele, R., 2015. An Investigation into Arctic Sea-Ice Dynamics and Energetics. Report submitted in partial fulfillment of the WHOI Summer Student Fellowship program. Unpublished manuscript.

PUBLICATIONS

The present grant provided partial support for the following research papers:

- Cole, S.T., M.-L. Timmermans, J.M. Toole, R.A. Krishfield and F.T. Thwaites, 2014. Ekman veering, internal waves, and turbulence observed under Arctic sea-ice. *Journal of Physical Oceanography*, doi: <http://dx.doi.org/10.1175/JPO-D-12-0191.1> [published, refereed]
- Cole, S.T., F.T. Thwaites, R.A. Krishfield, and J.M. Toole, 2015. Processing of Velocity Observations from Ice-Tethered Profilers. Proceedings Oceans 2015 MTS/IEEE, Washington, D.C. Oct 19-22, [in press]